The GPS global detection of the ionospheric response to solar flares

Afraimovich E. L.
Institute of Solar-Terrestrial Physics SD RAS,
p. o. box 4026, Irkutsk, 664033, Russia
fax: +7 3952 462557; e-mail: afra@iszf.irk.ru

Abstract

This author suggests the concept of a new technology for global detection (GLOBDET) of atmospheric disturbances of natural and technogenic origin, on the basis of phase measurements of the total electron content (TEC) in the ionosphere using an international GPS network. Temporal dependencies of TEC are obtained for a set of spaced receivers of the GPS network simultaneously for the entire set of "visible" (over a given time interval) GPS satellites (up to 5-10 satellites). These series are subjected to filtering in the selected range of oscillation periods using algorithms for spatio-temporal analysis of signals of non-equidistant GPS phased antenna arrays which are adequate to the detected disturbance. An analysis is made of the possibilities of using the GLOBDET when detecting the ionospheric response of solar flares. In this case it is best to make the coherent summation of the filtered series of TEC. A powerful impulsive flares of July 29, 1999 and December 28, 1999 were chosen to illustrate the practical implementation of the proposed method.

1 Introduction

The advent and evolution of a Global Positioning System, GPS, and also the creation on its basis of widely branched networks of GPS stations (at least 700 sites at the May of 2000, the data from which are placed on the INTERNET) opened up a new era in remote ionospheric sensing [13]. Furthermore, there exist also powerful regional networks such as the Geographical Survey Institute network in Japan [17] consisting of up to 1000 receivers. High-precision measurements of the group and phase delay along the line-of-sight (LOS) between the receiver on the ground and transmitters on the GPS system satellites covering the reception zone are made using two-frequency multichannel receivers of the GPS system at almost any point of the globe and at any time simultaneously at two coherently coupled frequencies $f_1 = 1575.42$ MHz and $f_2 = 1227.60$ MHz.

The sensitivity of phase measurements in the GPS system is sufficient for detecting irregularities with an amplitude of up to 10^{-3}–10^{-4} of the diurnal TEC variation. This makes it possible to formulate the problem of detecting ionospheric disturbances from different sources of artificial and natural origins. Anthropogenic sources of ionospheric disturbances include nuclear events, chemical explosions, and rocket launches. Among natural sources are solar eclipses, solar flares, earthquakes, volcanoes, heavy thunderstorms, and auroral heating. Studies of these phenomena are of great importance both for a scientific understanding of their genesis and propagation in the atmosphere

and as a tool for detecting such sources in remote regions; for instance, the GLONASS system provides more effective coverage at high latitudes [13].

Recently some authors embarked actively on the development of detection tools for the ionospheric response of powerful earthquakes [3], rocket launches [4], and industrial surface explosions [9]; [5]. Subsequetly, the GPS data began to be used in the context of the spaced-receiver method using three GPS stations to determine the parameters of the full wave vector of traveling ionospheric disturbances under quiet and disturbed geomagnetic conditions [1]; [2].

The limitations of the spaced-receiver method with a minimum necessary number of receivers (three) include their low sensitivity and inadequate spatial selectivity, and this gives no way of exploiting the potential of a global GPS system consisting of hundreds of GPS stations. Next in turn is the setting of a more general problem, namely, that of developing processing techniques for the data from the GPS and GLONASS systems, based on the latest achievements in the field of a comprehensive spatio-temporal processing of signals, with due regard for the special features of ionospheric disturbances, however.

The objective of this paper is to develop the concept of a global detector (GLOBDET) of atmosperic disturbances of natural and technogenic origins, based on phase measurements of total electron content (TEC) in the ionosphere using the international network of two-frequency multichannel receivers of the GPS system - section 2. Section 3 discusses the possibilities of using the GLOBDET method in detecting ionospheric effects of solar flares. Basic characteristics of such a detector (sensitivity and time resolution) are examined in Section 4. The practical implementation of the method is illustrated by analyzing a global ionospheric response to a powerful solar flares of July 29, 1999 and December 28, 1999 (Sections 5 and 6). Section 7 discusses the findings and explores the possibilities of utilizing a global GPS network in detecting other kinds of atmospheric disturbances of natural and technogenic origins.

2 Using the data from a global GPS network in the context of the ideology of a phased antenna array

Phased antenna arrays (FAA) are extensively used in radiolocation, sonar systems, and in processing seismic signals as systems featuring high sensitivity in signal detection and high spatial selectivity which is necessary for localizing signal sources. There exist quite varied schemes for hardware and software realization of FAA [6]. In general case the treatment of signals imply multiplying a complex signal $\tilde{A}(t)_i$ of each of the i–spaced FAA elements by a complex factor $\tilde{K}_i$ with the subsequent coherent summation of the resulting products

$$\tilde{S} = \sum_{i=1}^{N} \tilde{A}(t)_i \tilde{K}_i \tag{1}$$

where $\tilde{S}$ is the result of the coherent summation; i is the FAA element number; and i=1, 2, ...N.

By specifying different values of $\tilde{K}_i$, which in each particular case depend on the conditions of the problem being solved, it is possible to specify parameters determining the sensitivity and selectivity of FAA.

This author suggests the concept of a global detector (GLOBDET) of atmospheric disturbances of natural and technogenic origins, based on processing the GPS data in the FAA configuration. This concept implies that time dependencies of TEC are obtained for a set of spaced receivers of the GPS network simultaneously for all GPS satellites "visible" during a given time interval. These series are

subjected to filtering over a selected range of oscillation periods in order to eliminate slow variations caused by the orbital motion of the satellites and by the diurnal variation of TEC in the ionosphere. Next, these series are processed in the nonequidistant FAA configuration using them in (1) or in other algorithms of PAA as complex signals $\tilde{A}(t)_i$. It is also assumed that equivalent partial antennas of such an array are located at subionospheric points. The coordinates of these points are determined for the selected height h_{max} of the $F2$-layer maximum by means of standard (in the GPS system) calculations of the azimuth α and elevation θ of the LOS between the receiver and the satellite. α and θ are reckoned from the northward direction and from the ground, respectively.

The GPS technology provides the means of estimating TEC variations on the basis of phase measurements of TEC I in each of the spaced two-frequency GPS receivers using the formula [11]; [4]:

$$I = \frac{1}{40.308}\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}[(L_1\lambda_1 - L_2\lambda_2) + const + nL] \qquad (2)$$

where $L_1\lambda_1$ and $L_2\lambda_2$ are phase path increments of the radio signal, caused by the phase delay in the ionosphere (m); L_1, L_2 is the number of full phase rotations, and λ_1, and λ_2, are the wavelengths (m) for the frequencies f_1 and f_2, respectively; $const$ is some unknown initial phase path (m); and nL is the error in determination of the phase path (m).

The TEC unit, $TECU$, which is equal to 10^{16} m^{-2} and is commonly accepted in the literature, will be used throughout the text.

3 Using the GLOBDET technology in detecting the ionospheric response to solar flares

The enhancement of X-ray and ultraviolet radiation intensity that is observed during chromospheric flares on the Sun immediately causes an increase in electron density in the ionosphere. These density variatiuons are different for different altitudes and are collectively called Sudden Ionospheric Disturbances (SID). SID observations provide a key means for ground-based detection of solar flares along with optical observations of flares and solar radio burst observations. Much research is devoted to SID studies, among them a number of thorough reviews and monographs [16].

SID data for the F-region acquired by different radio probing methods were used repeatedly to estimate time variations in the X-ray and extreme ultraviolet (EUV) spectral regions and in relative measurements of fluxes in different wavelength ranges [8]; [18]; [15]. The main body of SID data for the Earth's upper atmosphere was obtained in earlier detections of Sudden Frequency Deviations (SFD) of the F-region-reflected radio signal in the HF range [7]; [8].

A further, highly informative, technique is the method of incoherent scatter (IS) [18]. However, the practical implementation of the IS method requires very sophisticated, expensive equipment. An added limitation is inadequate time resolution. Since the relaxation time of electron density in the E- and $F1$-regions is also less than 5-10 min, most IS measurements lack time resolution needed for the study of inospheric effects of flares.

The effect of solar flares on the ionospheric F-region is also manifested as a Sudden Increase of Total Electron Content (SITEC) which was measured previously using continuously operating radio beacons on geostationary satellites [15]. A serious limitation of methods based on analyzing VHF signals from geostationary satellites is their small and ever increasing with the time number and the nonuniform distribution in longitude.

Consequently, none of the above-mentioned existing methods can serve as an effective basis for the radio detection system to provide a continuous, global SID monitoring with adequate space-time resolution. Furthermore, the creation of these facilities requires developing special-purpose equipment, including powerful radio transmitters contaminating the radio environment. It is also significant that when using the existing methods, the inadequate spatial aperture gives no way of deducing the possible spatial inhomogeneity of the X-ray and EUV flux.

According to the above concept, a global GPS network can be successfully used as a global detector of the ionospheric response to solar flares. A physical groundwork for the method is formed by the effect of fast change in electron density in the Earth's ionosphere at the time of a flare simultaneously on the entire sunlit surface.

Essentially, the method implies using appropriate filtering and a coherent processing of TEC variations in the ionosphere simultaneously for the entire set of "visible" (during a given time interval) GPS satellites (as many as 5-10 satellites) at all global GPS network stations used in the analysis. In detecting solar flares, the ionospheric response is virtually simultaneous for all stations on the dayside of the globe within the time resolution range of the GPS receivers (from 30 s to 0.1 s). Therefore, the coherent addition of individual realizations $\tilde{A}(t)_i$ does not require a partial phase shift (the complex part of the term $\tilde{K}_i$ is zero), and the entire procedure reduces to a simple addition

$$\tilde{S} = \sum_{i=1}^{N} \tilde{A}(t)_i K_i \tag{3}$$

where $\tilde{A}(t)_i$ represents filtered TEC variations, and K_i is the amplitude weighting factor determined by the geometry of the i -beam (LOS) to the satellite. To a first approximation, this factor is [12].

$$K_i = cos\left[arcsin\left(\frac{R_z}{R_z + h_{max}} cos\theta_i\right)\right] \tag{4}$$

where R_z is the Earth's radius; $h_{max} = 300$ is the height of the $F2$–layer maximum.

Reconstructing the absolute value of the ionospheric response to the solar flare requires a more accurate (than used in this paper) conversion of the "oblique" TEC value to a "vertical" one, especially at low values of elevations of the beam to the satellite. To do this, it is necessary not only to eliminate, for this beam to the satellite, the ambiguity of the determination of the absolute TEC value which arises when only phase measurements are used in the GPS system. The response can only be estimated reliable, with the inclusion the spatially inhomogeneous ionosphere, by using all beams to the satellite, and by applying adequate methods of spatial interpolation. This problem is considered in a series of publications (for example, [14]) and is beyond the scope of this paper.

4 Characteristics of a global detector

The detection sensitivity is determined by the ability to detect typical signals of the ionospheric response to a solar flare (leading edge duration, period, form, length) at the level of TEC background fluctuations. Ionospheric irregularities are characterized by a power spectrum, so that background fluctuations will always be distinguished in the frequency range of interest. However, background fluctuations are not correlated in the case of beams to the satellite spaced by an amount exceeding the typical irregularity size.

With a typical length of X-ray bursts and EUV emission of solar flares of about 5-10 min, the

a statistical independence of TEC fluctuations at spaced beams is almost always satisfied. Therefore, coherent summation of responses to a flare on a set of beams spaced thoughout the dayside of the globe permits the solar flare effect to be detected even when the response amplitude on partial beams is markedly smaller than the noise level (background fluctuations). The proposed procedure of coherent accumulation is essentially equivalent to the operation of coincidence schemes which are extensively used in X-ray and gamma-ray telescopes.

If the SID response and background fluctuations, respectively, are considered to be the signal and noise, then as a consequence of a statistical independence of background fluctuations the signal/noise ratio when detecting the flare effect is increased through a coherent processing by at least a factor of $\sqrt{N}$, where N is the number of LOS.

The solar flares of July 29, 1999 and Decevber 28, 1999 were used to illustrate the performance of the proposed method. Fig.1a presents the geometry of a global GPS array used in this paper to analyze the effects of the July 29, 1999 flare (105 stations). Heavy dots correspond to the location of the GPS stations. The upper scale indicate the local time, LT, corresponding to 19:00 UT. The coordinates of the stations are not given here for reasons of space.

As is evident from Fig. 1a, the set of stations which we chose out of the global GPS network available to us, covers rather densely North America and Europe, but provides much worse coverage of the Asian part of the territory used in the analysis. The number of GPS stations in the Pacific and Atlantic regions is even fewer. However, coverage of the territory with partial beams to the satellite for the limitation on elevations $\theta > 10^\circ$, which we have selected, is substantially wider. Dots in Fig. 1a mark the coordinates of subinospheric points for the height of the $F2$–layer maximum $h_{max} = 300$ km for all visible satellites at 19:00 UT for each GPS station. A total number of beams (and subionospheric points) used in this paper to analyze the July 29, 1999 flare is 622.

Fig.1b presents the geometry of a global GPS array used in this paper to analyze the effects of the December 28, 1999 solar flare, (230 stations; only for the dayside). A total number of beams (and subionospheric points) is 1200.

Such coverage of the terrestrial surface makes it possible to solve the problem of detecting time-coincident events with spatial resolution (coherent accumulation) two orders of magnitude higher, as a minimum, than could be achieved in SFD detection on oblique HF paths. For simultaneous events in the western hemisphere, the correspoding today's number of stations and beams can be as many as 400 and 2000–3000, respectively.

It should be noted that because of the relatively low satellite orbit inclinations, the GPS network (and to a lesser degree GLONASS) provides poor coverage of the Earth's surface near the poles. However, TEC measurements in the polar regions are ineffective with respect to the detection of the ionospheric response to a solar flare because the amplitude of background fluctuations in this case is much higher when compared with the mid-latitude ionosphere. This is partiocularly true of geomagnetic disturbance periods. For the same reason, equatorial stations should also be excluded from a coherent processing.

If the Earth's ionosphere is regarded as the filling of some global detector of X-ray and EUV emissions, then it is possible to estimate a huge volume V_{det} of the potential sensitivity region of such a detector. This volume is equal to one-half the difference of the volumes of spheres with the radii $R_z + H_{max}$ and $R_z + H_{min}$

$$V_{det} = 2\pi[(R_z + H_{max})^3 - (R_z + H_{min})^3]/3 \quad (5)$$

where H_{min} and H_{max} are the upper and lower boundaries of the absorbing layer for a given part of the flare emission spectrum. For the EUV range, $H_{min} = 100$ km, and $H_{max} = 200$ km [16], which

gives the volume V_{det} of order $2.65\,10^{19}$ m^3. For the X-ray part of the spectrum, $H_{min} = 60$ km, and $H_{max} = 80$ km [16], and the corresponding volume is $0.523\,10^{19}$ m^3.

The actual sensitivity is in fact determined by the number of beams penetrating the region of potential sensitivity. Furthermore, solar flare-induced TEC perturbations constitute but a small part of TEC including the height range up to 1000 km. There are methods to estimate the height in the ionosphere, but they do not come within the province of this paper.

On the one hand, GLOBDET time resolution is limited by technical capabilities of the GPS system. Essentially, data with a time resolution of about 30 s are currently available on the INTERNET, which is insufficient for a detailed analysis of the fine structure of the SID time dependence. Yet this limitations seems to be transient since current multichannel two-frequency GPS receivers can operate with a time resolution of up to 0.1 s.

On the other hand, time resolution is determined by time constants of ionization and recombination processes in the ionosphere at a given height [8], [16]; these parameters can be taken into acount when processing the data.

5 Ionospheric response to the solar flare of July 29, 1999

A powerful impulsive flare of July 29, 1999 was chosen to illustrate the practical implementation of the proposed method. The thick line in Fig. 2d shows the time dependence of the X-ray emission intensity $R(t)$ of this flare as measured by the X-telescope BATSE on satellite CGRO in 25–50 keV range. The envelope of the dependence $R(t)$ represents a bell-shaped pulse of about 3-min duration with a maximum corresponding to 19:34 UT, or to about 12:00 LT in the U.S. West (Fig. 1a). This time interval is characterized by a low level of geomagnetic disturbance (within -10 nT), which simplified greatly the SID detection problem.

We now describe briefly the sequence of GPS data processing procedures. Primary data include series of "oblique" values of TEC $I(t)$, as well as the corresponding series of elevations $\theta(t)$ and azimuths $\alpha(t)$ along LOS to the satellite calculated using our developed CONVTEC program which converts the GPS system standard RINEX-files on the INTERNET [10]. The determination of SID characteristics involves selecting continuous series of $I(t)$ measurements of at least a one-hour interval in length, which includes the time of the flare. Series of elevations $\theta(t)$ and azimuths $\alpha(t)$ of the beam to the satellite are used to determine the coordinates of subionospheric points. In the case under consideration, all results were obtained for elevations $\theta(t)$ larger than 10°.

Fig. 2a presents typical time dependencies of an "vertical" TEC $I(t)$ for the PRN03 satellite at the CME1 station (40.4°N; 235.6°E) on July 29, 1999 (thick line) and for PRN21 at the CEDA station (40.7°N; 247.1°E – thin line). It is apparent from Fig. 2a that in the presence of slow TEC variations, the SID-induced short-lasting sudden increase in TEC is clearly distinguished in the form of a "step" as large as 0.4 $TECU$.

For the same series, similar lines in panel b. show variations of the time derivative of TEC $dI(t)/dt$ with the linear trend removed and with a smoothing with the 5-min time window. The TEC time derivative is invoked because it reflects electron density variations which are proportional to the X-ray or EUV flux [16].

The coherent summation of $dI(t)/dt_i$ realizations was made by the formula

$$S(t) = \sum_{i=1}^{N} dI(t)/dt_i K_i \tag{6}$$

The (normalized to N) result of a coherent summation of the $S(t)$-series for all beams and GPS

stations located mainly on the dayside is presented in panel c (thick line). A comparison of the resulting coherent sum of $S(t)$ with the time dependence $dI(t)/dt$ for individual beams presented in panel b. confirms the effect of a substantial increase of the signal/noise ratio caused by a coherent processing.

It is interesting to compare, for the same time interval, the results from a coherent summation for the dayside and nightside. The r.m.s. of the coherent sum of $S(t)$ in panel c. for the nightside (thin line) is an order of magnitude (as a minimum) smaller than the SID response amplitude.

A comparison of the coherent sum of $S(t)$ with the time dependence of the X-ray emission intensity $R(t)$ of the July 29, 1999 flare, based on the data from the X-telescope BATSE on satellite CGRO data in 25–50 keV range (panel d), shows their high correlation and an almost total coincidence of the form of $S(t)$ with the $R(t)$ pulse envelope.

It should be noted, however, that generally TEC variations $S(t)$ are 60 s ahead of $R(t)$. It is pointed out in [16] that EUV emission is mostly responsible for SID in the F-region, TEC variations are also well correlated with X-ray flares. This is also confirmed by simultaneous measurements of flare emission characteristics in the X-ray and EUV ranges by the Solar Maximum Mission spacecraft [19]. It is also observed in [16] that the EUV emission flare does lead (but only slightly) the X-ray flare.

6 Ionospheric response to the solar flare of December 28, 1999

A powerful impulsive flare of December 29, 1999 was chosen also to illustrate the practical implementation of the proposed method. The dashed line in Fig. 3d shows the time dependence of the X-ray emission intensity $R(t)$ of this flare as measured by the X-telescope BATSE on satellite CGRO in 25–50 keV range (thin line). The envelope of the dependence $R(t)$ represents a bell-shaped pulse of about 1.5-min duration with a maximum corresponding to 00:44 UT, or to about 16:00 LT in the U.S. West (Fig. 1b). This time interval is characterized by a low level of geomagnetic disturbance (within - 22 nT), which simplified greatly the SID detection problem. The December 28, 1999 flare was also recorded by X-ray telescope HXT on the YOHKOH satellite (Fig. 3d - thick line; in 23-33 keV range).

Fig. 3a presents typical time dependencies of an "vertical" TEC $I(t)$ for the PRN26 satellite at the LEEP station (39.1°N; 241.7°E) on December 28, 1999 (thick line) and for PRN04 at the CHI1 station (60.2°N; 213.3°E – thin line). It is apparent from Fig. 3a that in the presence of slow TEC variations, the SID-induced short-lasting sudden increase in TEC is clearly distinguished in the form of a "step" as large as 0.2–0.5 $TECU$.

For the same series, similar lines in panel b. show variations of the time derivative of TEC $dI(t)/dt$ with the linear trend removed and with a smoothing with the 5-min time window.

The (normalized to N) result of a coherent summation of the $S(t)$-series for all beams and GPS stations located mainly on the dayside is presented in panel c (thick line).

A comparison of the coherent sum of $S(t)$ with the time dependence of the X-ray emission intensity $R(t)$ of the December 28, 1999 flare, based on the data from the X-telescopes BATSE on satellite CGRO data in 25–50 keV range and HXT on the YOHKOH satellite in 14-23 keV range (panel d), shows their high correlation and an almost total coincidence of the form of $S(t)$ with the $R(t)$ pulse envelope.

7 Discussion and conclusions

This paper has offered a brief outline of the concept of a global detector (GLOBDET) of atmospheric disturbances, based on phase measurements of a TEC in the ionosphere which were made using the international network of two-frequency multichannel GPS receivers. We have discussed the possibilities of using GLOBDET method in detecting ionospheric effects of solar flares. A case study of a global ionospheric response to a powerful solar flares of July 29, 1999 and December 28, 1999 illustrates the new experimental potential.

The GLOBDET technology, suggested in this paper, can be used to detect small solar flares; the body of data processed is the only limitation in this case. The high sensitivity of GLOBDET permits us to propose the problem of detecting, in the flare X-ray and EUV ranges, emissions of nonsolar origins which are the result of supernova explosions.

For powerful solar flares like the one examined in this report, it is not necessary to invoke a coherent summation, and the SID response can be investigated for each beam. This opens the way to a detailed study of the SID dependence on a great variety of parameters (latitude, longitude, solar zenith angle, spectral characteristics of the emission flux, etc.). With current increasing solar activity, such studies become highly challenging. In adidtion to solving traditional problems of estimating parameters of ionization processes in the ionosphere and problems of reconstructing emission parameters [16], the data obtained through the use of GLOBDET can be used to estimate the spatial inhomogeneity of emission fluxes at scales of the Earth's radius.

The GLOBDET technology can also be used in detecting disturbances of natural and technogenic origins accompanied by the propagation of acoustic and acoustic-gravity waves. They include such phenomena as explosions, rocket launches, solar eclipses, the displacement of the solar terminator, earthquakes, volcanic eruptions, heavy thunderstorms, and auroral heating. Unlike solar flares, however, the response to the above-mentioned effects is not time-coincident for different beams. Therefore, when selecting complex factors $\tilde{K}_i$, it is necessary to appropriately take into account the amplitude attenuation and the phase delay which are caused by the propagation decay and finite velocity (sonic and subsonic in this case) of the response in the ionosphere. Furthermore, a processing of traveling TEC disturbances implies essentially using regional rather than global GPS networks, which reduces the sample statistic of the beams when the signal is accumulated.

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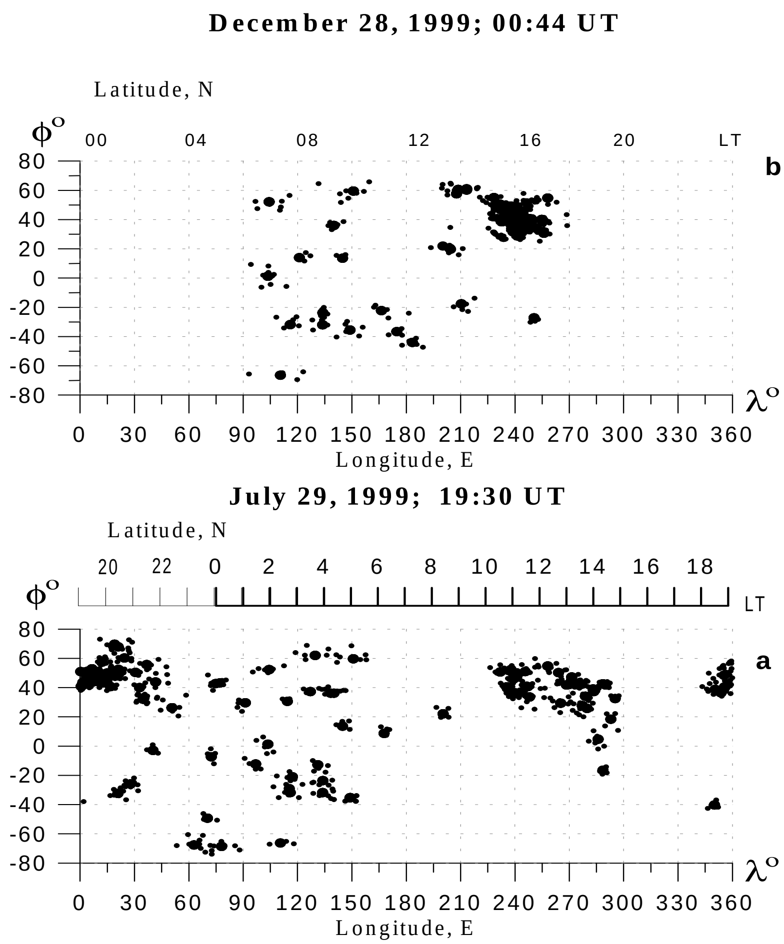

Figure 1: Geometry of the GPS array used in this paper when analyzing the effects of the July 29, 1999 solar flare (105 stations) – **a** . Heavy dots correspond to the location of the GPS stations. The upper scale indicates the local time, LT, corresponding to 19:00 UT. Dots show the coordinates of subionospheric points for the height of the $F2$–layer maximum, $h_{max} = 300$ km for all satellites seen at 19:00 UT for each of the GPS stations. A total number of beams (and subionospheric points) is 622. Same as in Fig.1a, but for the December 28, 1999 solar flare (230 stations; only for the dayside) – **b**. The upper scale indicates the local time, LT, corresponding to 00:00 UT. A total number of beams is 1200.

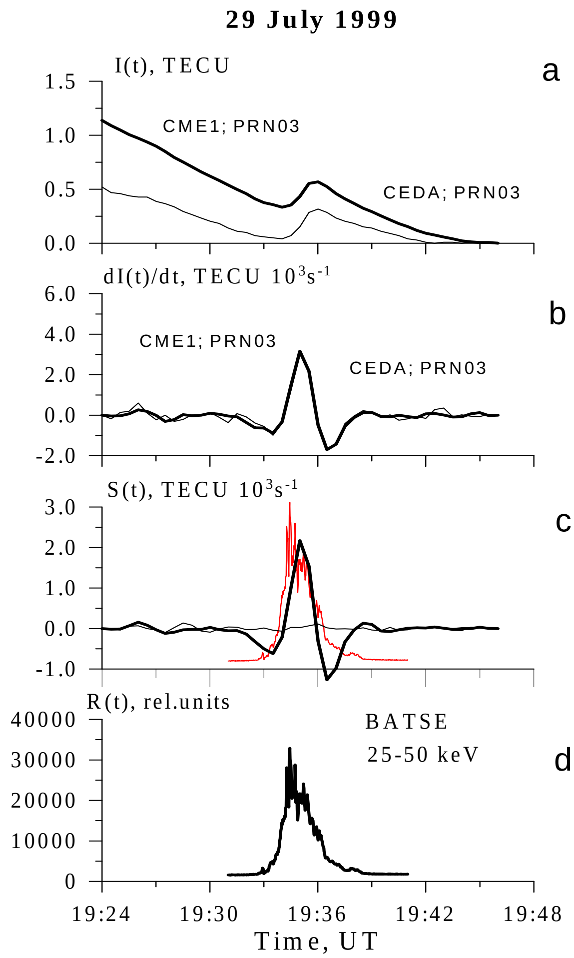

Figure 2 : Time dependences of TEC on the dayside $I(t)$ on July 29, 1999 – **a**, and variations of the time derivative $dI(t)/dt$ with the linear trend removed and a smothing with the 5-min time window –**b**, for stations CME1 (PRN03–thick line) and CEDA (PRN21–thin line). The normalized coherent sum of variations of the TEC time derivative $S(t)$ for all LOS for the dayside – **c** (thick line). For comparison, thin line in panel c. show $S(t)$ for the nightside. **d** – X-ray emission intensity variations $R(t)$ as deduced from the X-telescope BATSE on satellite CGRO data in 25–50 keV range.

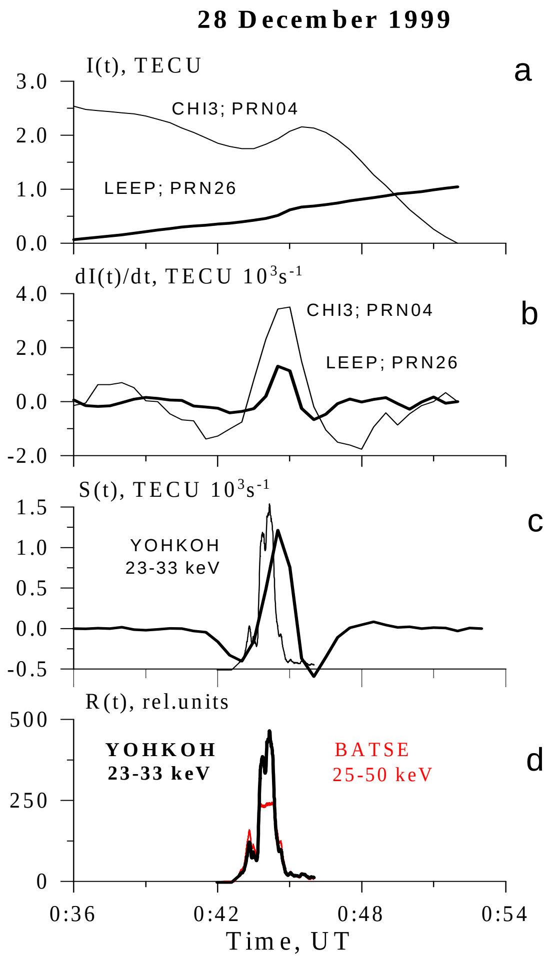

Figure 3 : Time dependences of TEC on the dayside $I(t)$ on December 28, 1999 – **a**, and variations of the time derivative $dI(t)/dt$ with the linear trend removed and a smothing with the 5-min time window – **b**, for stations LEEP (PRN26–thick line) and CHI1 (PRN04–thin line). The normalized coherent sum of variations of the TEC time derivative $S(t)$ for all LOS for the dayside – **c** (thick line). For comparison, the thin line in panel **d** show X-ray emission intensity variations $R(t)$ as deduced from the X-telescope BATSE on satellite CGRO data in 25–50 keV range. Thick line show X-ray emission variations $R(t)$ as deduced from the X-ray telescope HXT on the YOHKOH satellite in 23-33 keV.